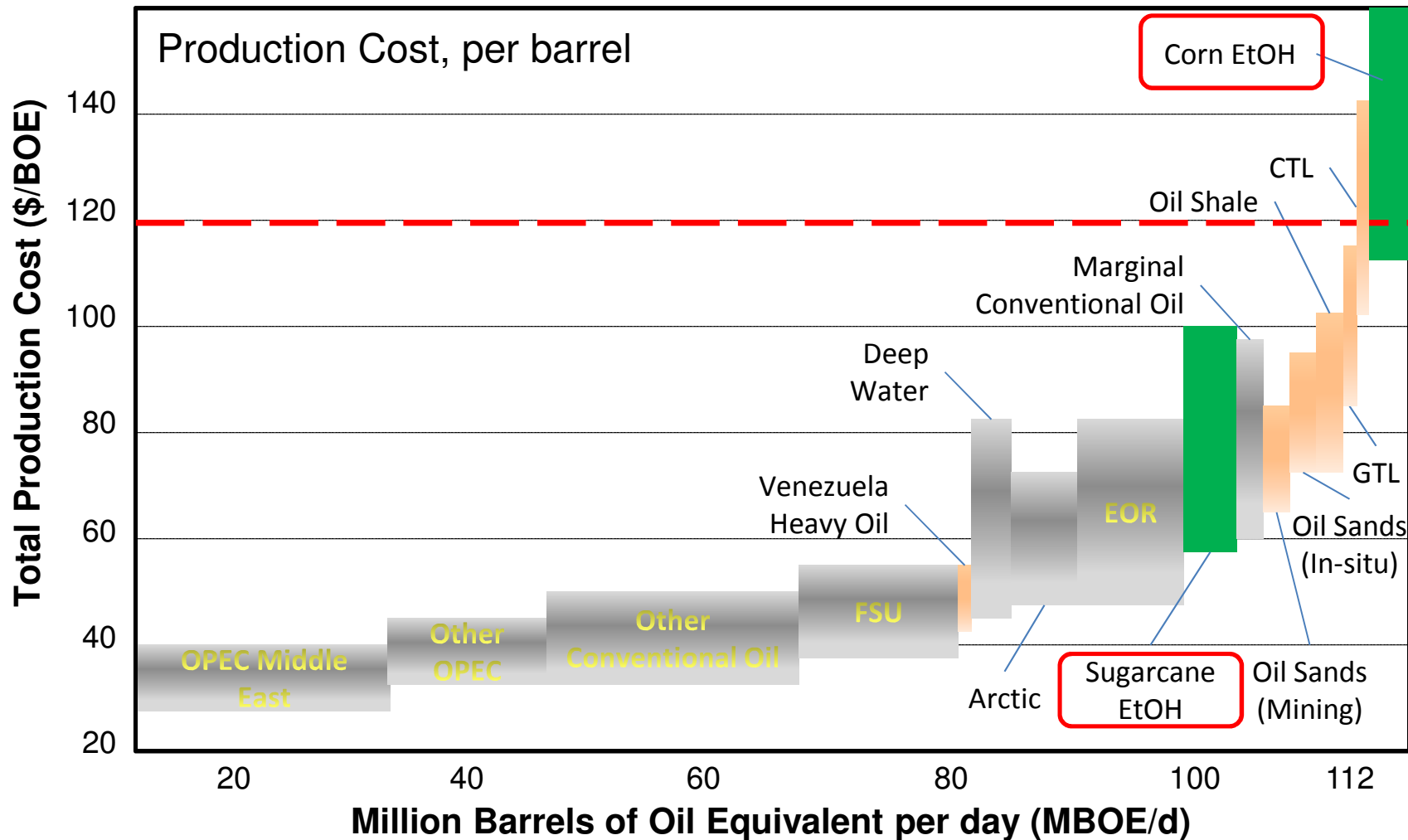


# Bioenergy Workshop Session

Eric Toone  
Jonathan Burbaum

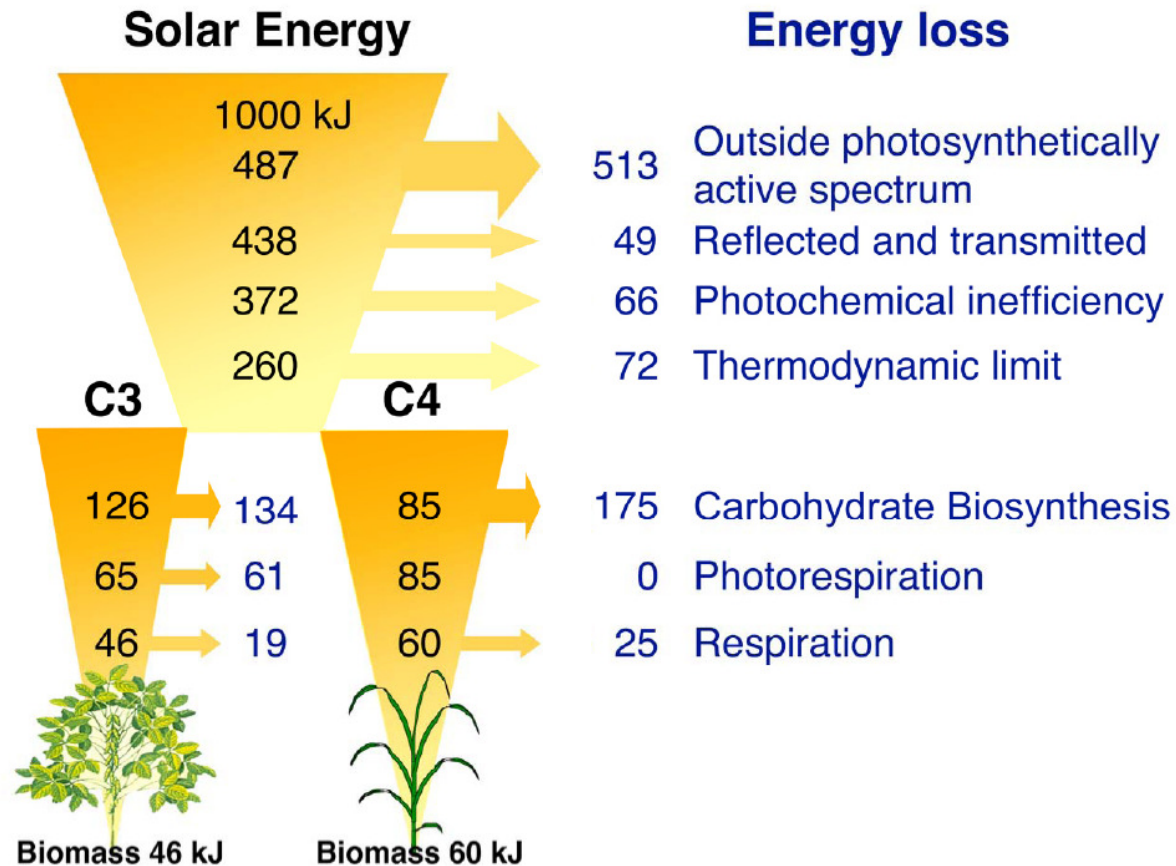
February 27, 2012

# Biofuels: A tough nut to crack



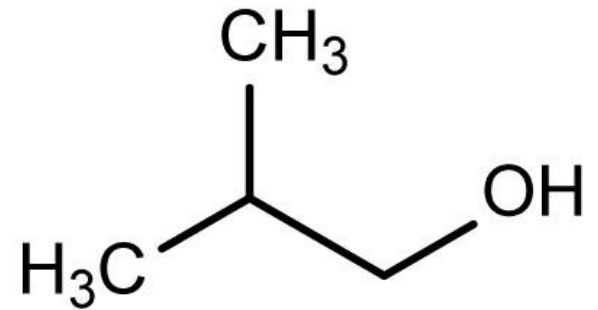
Source: Booz Allen Hamilton analysis based on information from IEA, DOE and interviews with super-majors

# Current pathways for liquid fuels from solar energy have low energy efficiency

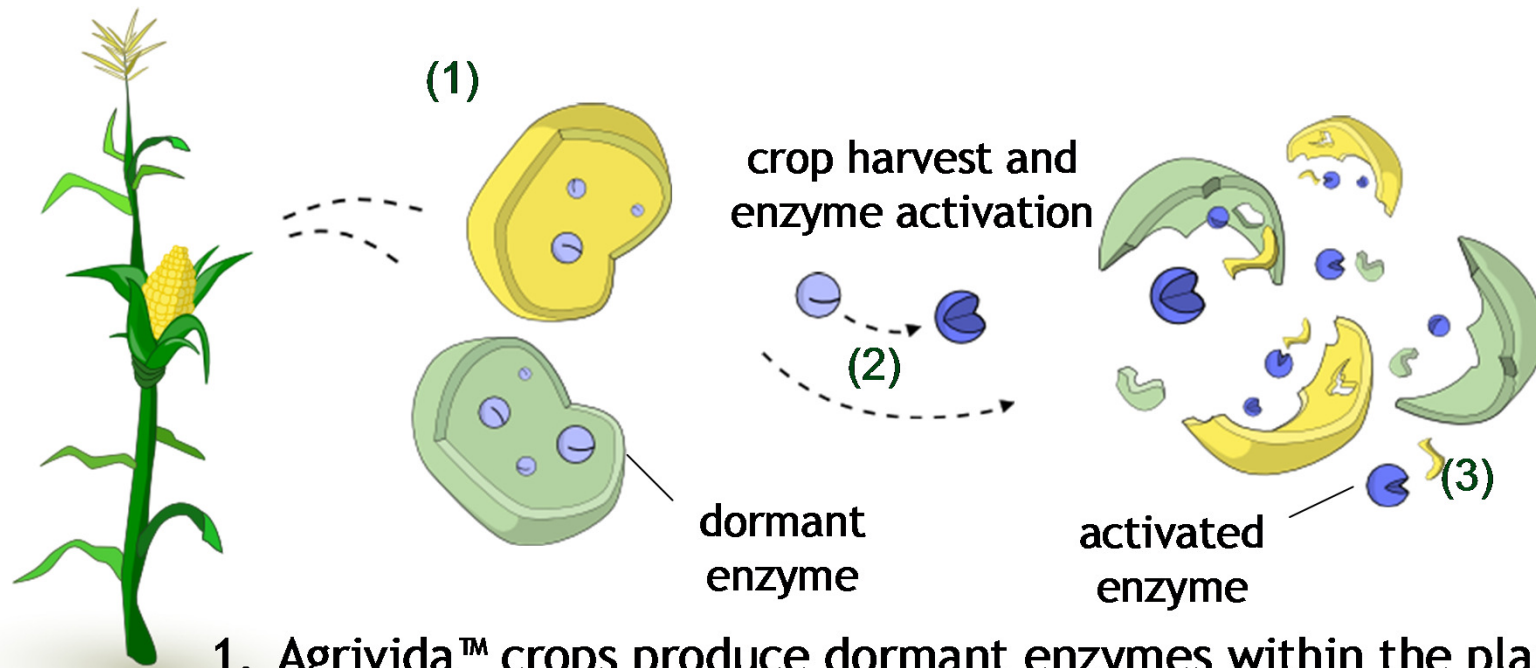


Zhu et al. *Current Opinion in Biotechnology* (2008)  
19:153-159

# Scalable production of macroalgae as a feedstock for isobutanol



# Diminishing biomass pre-treatment costs through plant biotechnology

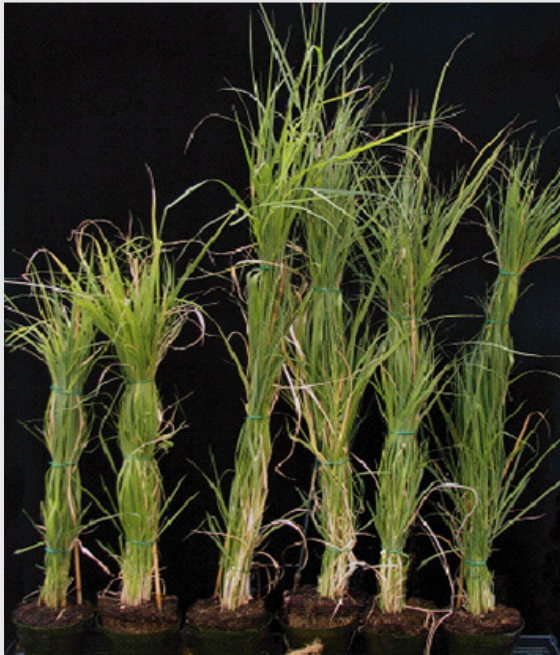


1. Agrivida™ crops produce dormant enzymes within the plant.
2. The dormant enzymes are activated after harvest.
3. The activated enzymes degrade the cell wall.

**Agrivida**

# Developing high biomass dedicated energy crops with increased nitrogen use efficiency

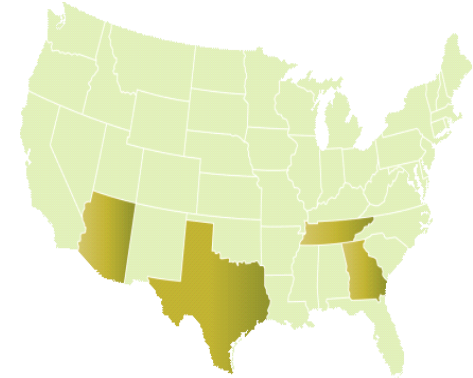
4 HIGH BIOMASS NUE TRAITS



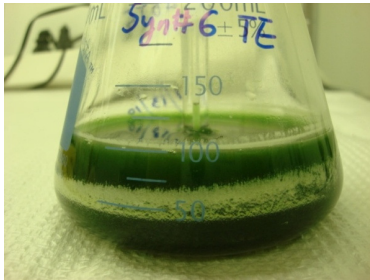
DEDICATED ENERGY CROPS



FIELD TRIALS IN 4 STATES



# Economically-viable algae systems technologies suitable for deployment

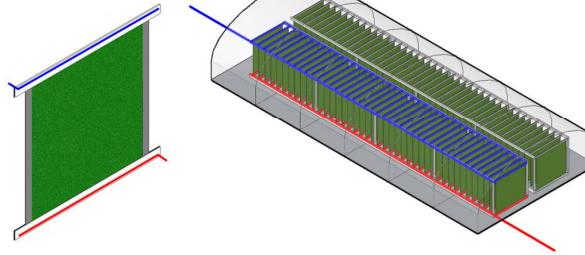


Biocatalyst  
development



Coating-enabled  
bioartificial leaves...

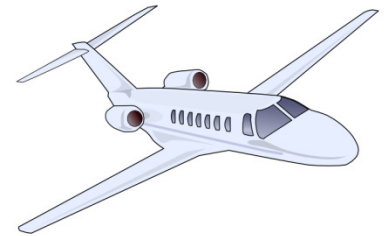
...arranged at high  
density



Smart Flow Photobioreactor



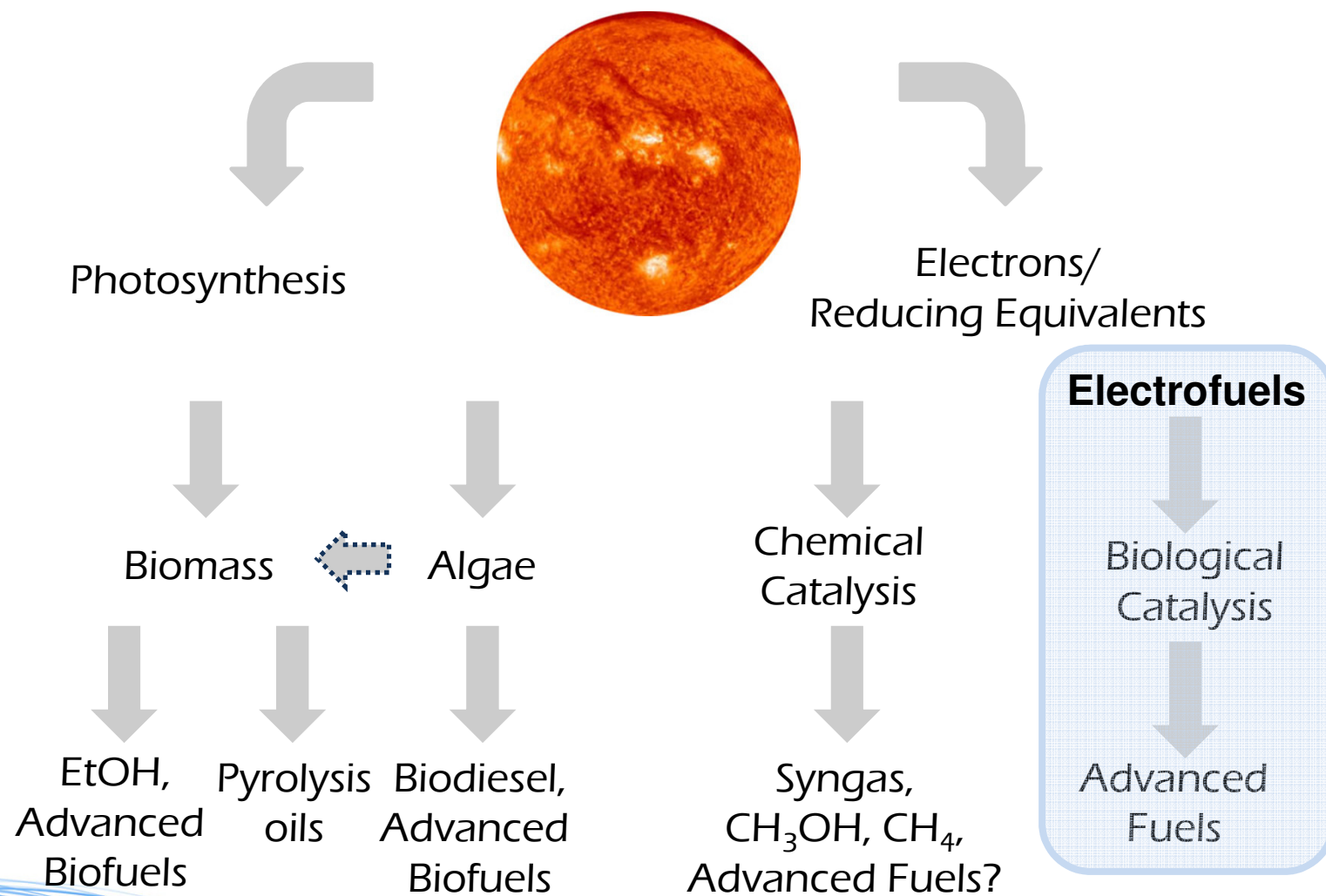
Current Test Unit



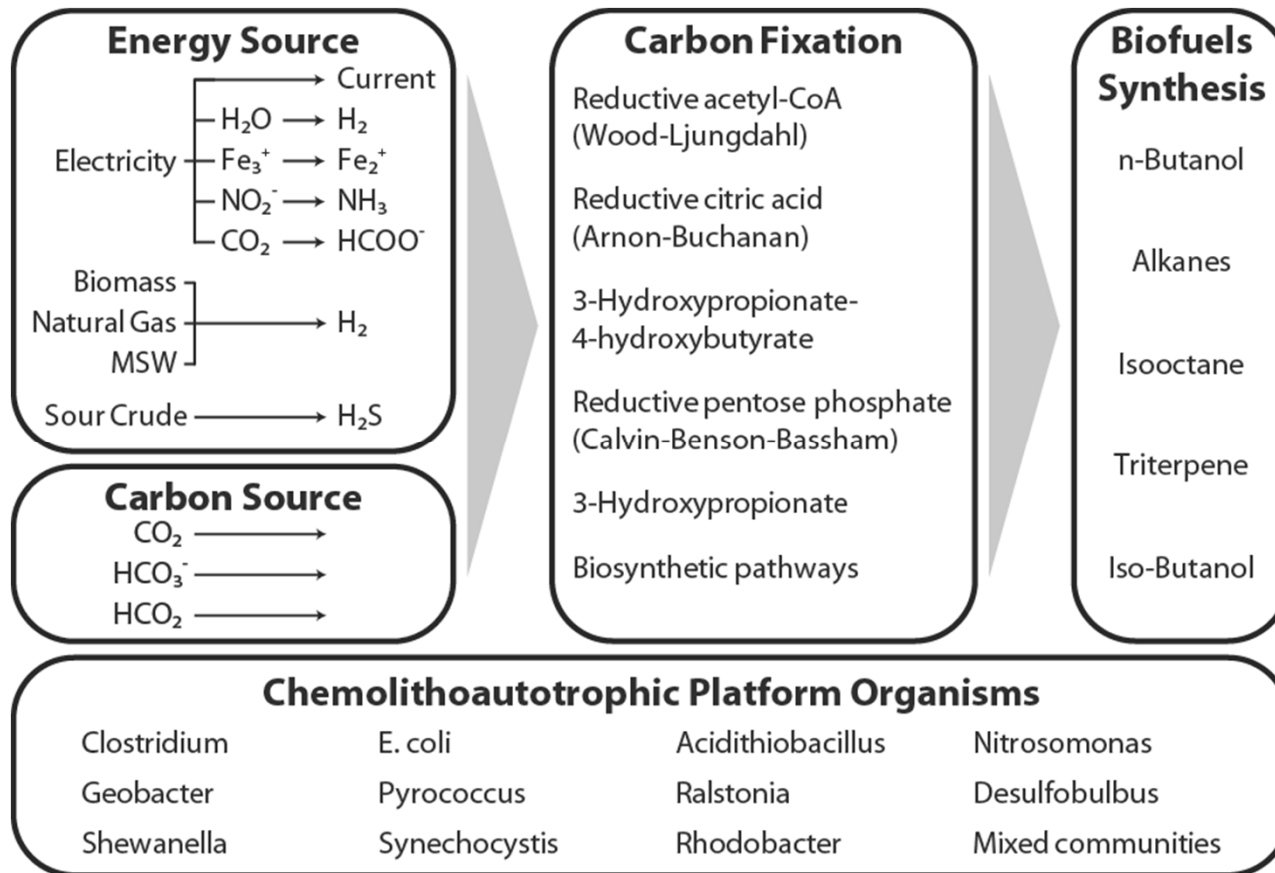
Upgrading to  
jet fuel



# ARPA-E seeks new biofuels programs to address current biofuel production inefficiencies



# Chemolithoautotrophs are at the core of a efficient and flexible Electrofuels platform



Source: Conrado, R.J., Haynes, C.A., Haendler, B.E., Toone, E.J., "Electrofuels: A New Paradigm for Renewable Fuels" 2011, *Advanced Biofuels and Bioproducts (in press)* (Lee, J., ed.): Springer, U.S.

# H<sub>2</sub> consuming bacteria



Autotrophic production

Free fatty acid extraction

Final fuel upgrading

# Electrochemically produced formate

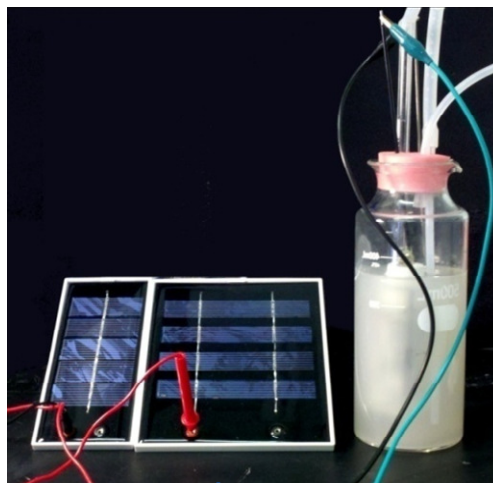
Photovoltaic

or

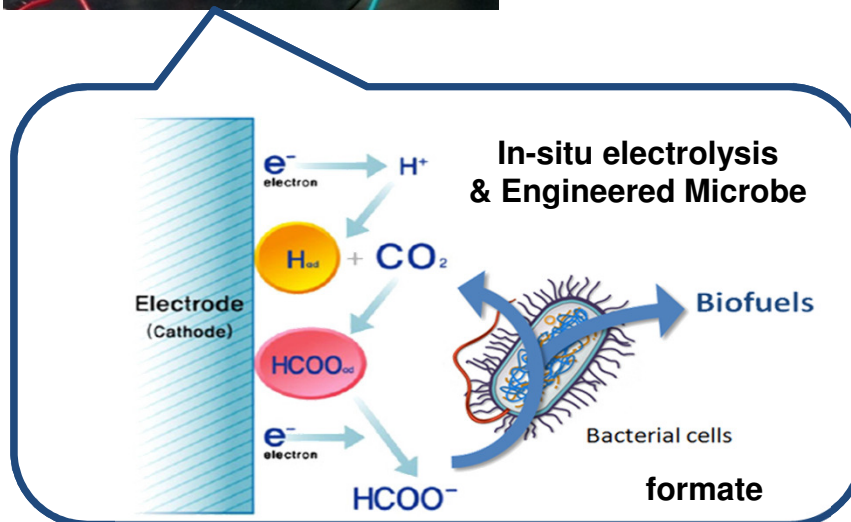
Electricity

$\text{CO}_2$

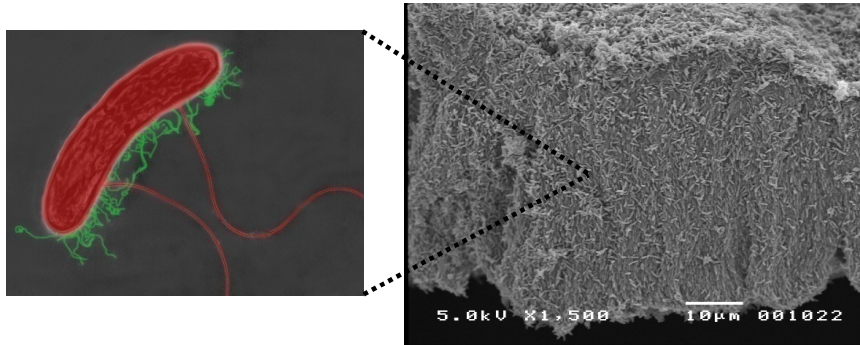
UCLA



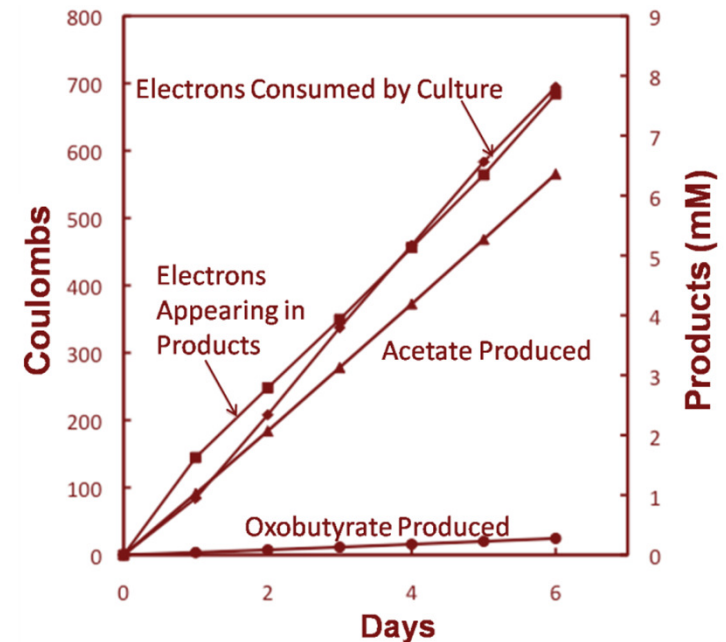
Gasoline  
substitutes



# Direct current/biocathodes



*Geobacter metallireducens*  
can form conductive biofilms on the  
surface of electrodes

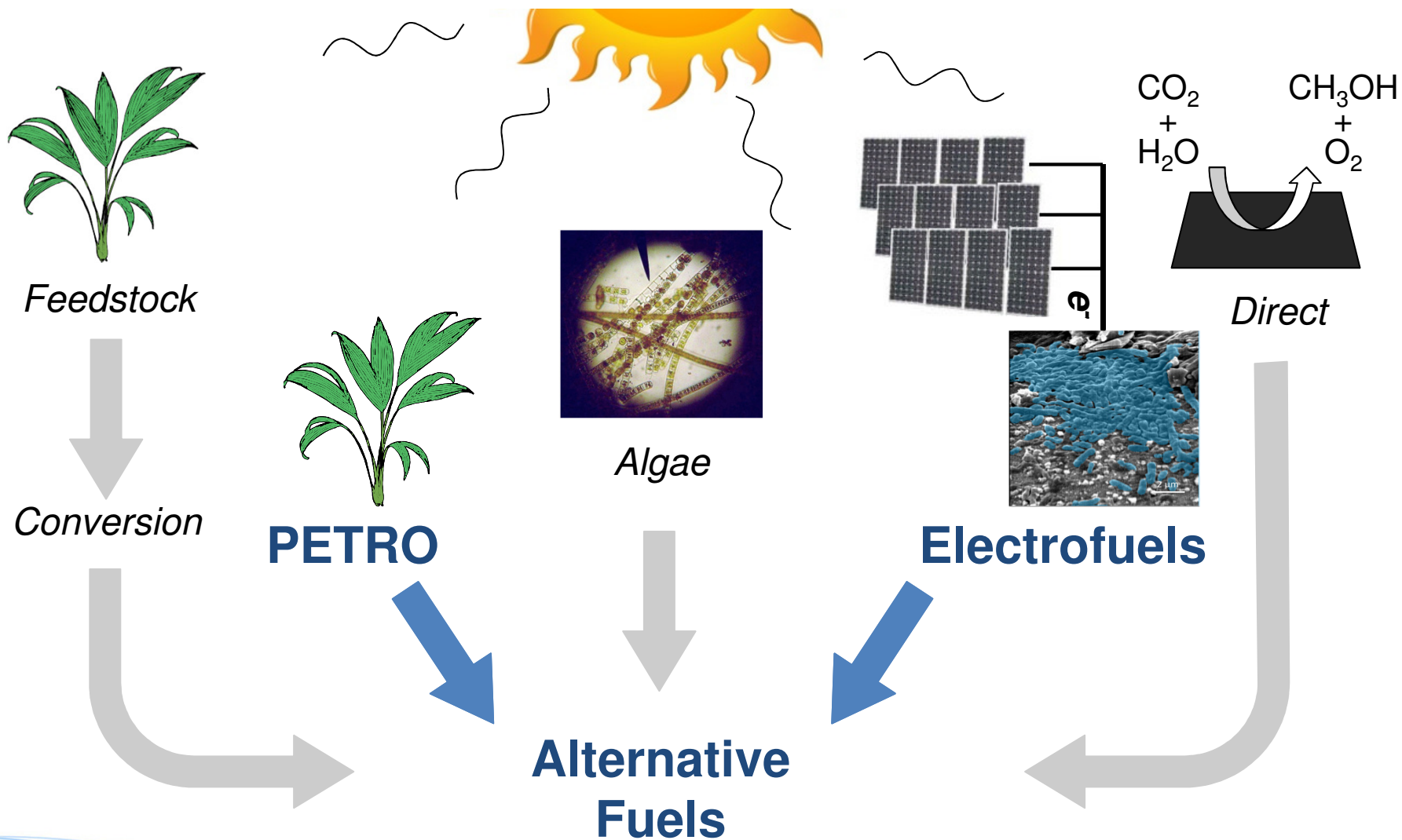


Acetogenes have demonstrated the  
ability to produce acetate directly  
from electrons with high coulombic  
efficiency



**PETRO** 

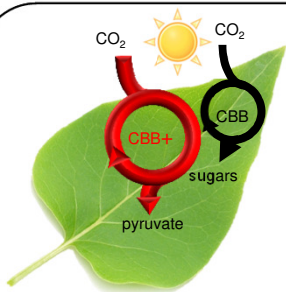
# Programs focus on white spaces in biofuel production



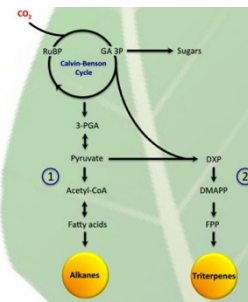
# PETRO

Plants Engineered To Replace Oil

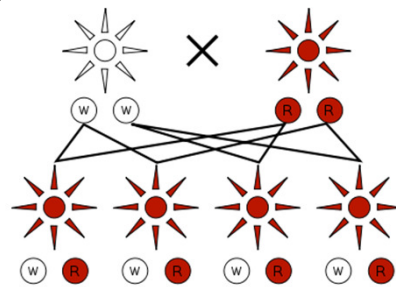
## Developing Dedicated Biofuel Crops



Photosynthesis  
Optimization



Metabolic  
engineering



Heritable  
Traits

Yield: 160 GJ/Ha-year (2x corn)

Cost: < \$3 GGE

# Plants being developed under PETRO



**Oilseed**



(*Camelina*)



**C<sub>4</sub> Grasses**



(sugarcane, sorghum)

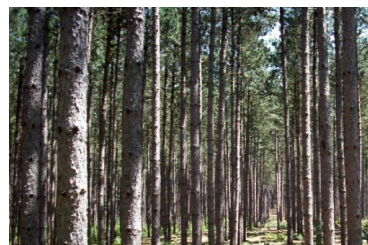


**Arcadia**  
BIOSCIENCES  
(*Setaria* → sorghum)



**UCLA**

(*Arabidopsis* → Switchgrass)



**Trees**



(loblolly pine)



**Other**



(tobacco)



(tobacco → Giant cane)



# Pine trees engineered to produce fuel molecules in addition to providing pulp for paper

Increase production, fuel quality & storage capacity for pine terpenes



**Loblolly pine**



**Ancient source of turpentine**



**Processed on an industrial scale**

**UF** UNIVERSITY of FLORIDA

ARBORGEN<sup>®</sup>

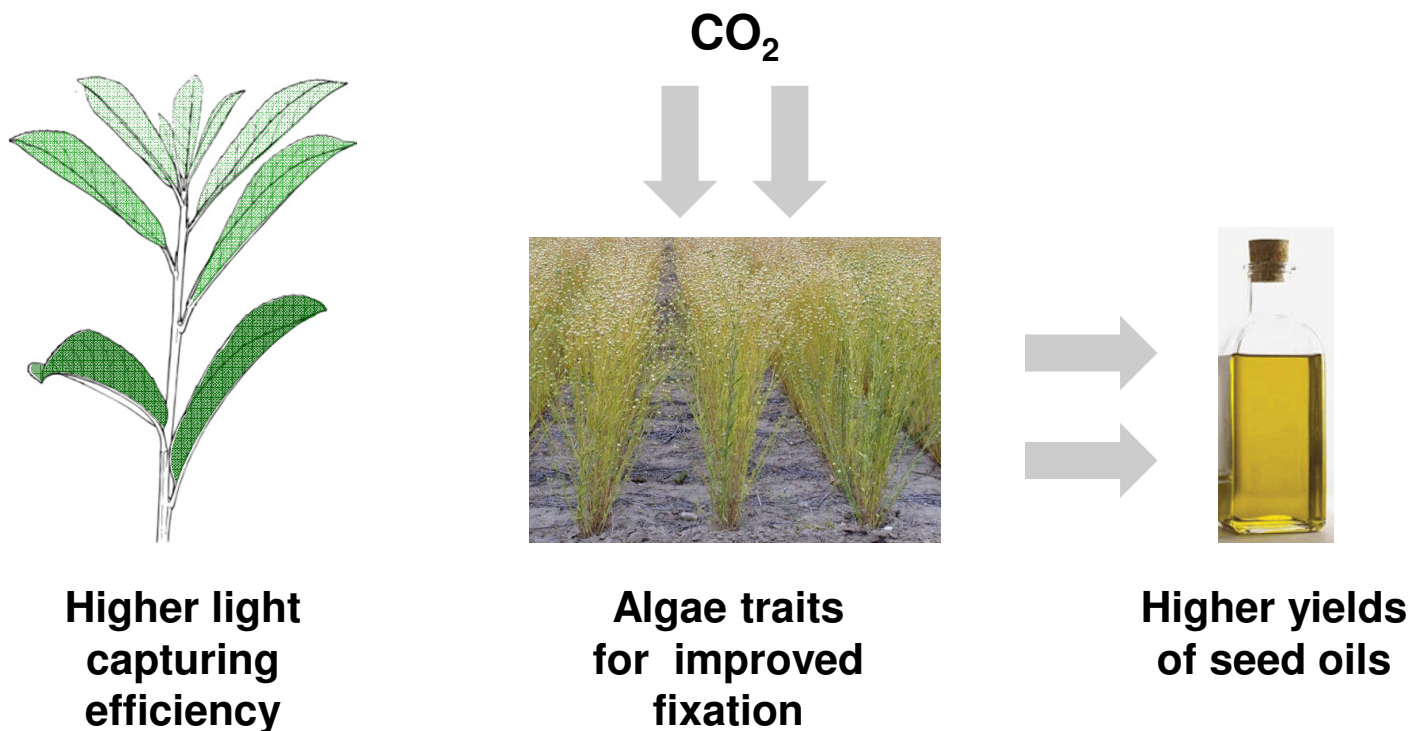
**NREL**  
NATIONAL RENEWABLE ENERGY LABORATORY

**Berkeley**  
University of California

arpa·e

**PETR**

# Higher yield *Camelina* with improved energy & CO<sub>2</sub> capture



# Sorghum engineered to produce fuel



Sweet Sorghum



...engineered...



to make fuel,  
instead of sugar



# Questions?



- What approaches are missing?
- How else can biology be used to transform the energy landscape?

**Please note, this is not an opportunity to discuss specific technologies**